



# Observation Sensitivity Experiments with the Hourly Rapid Refresh (RAP) Using Hybrid- Ensemble/Variational Data Assimilation

*Eric James, Stan Benjamin*

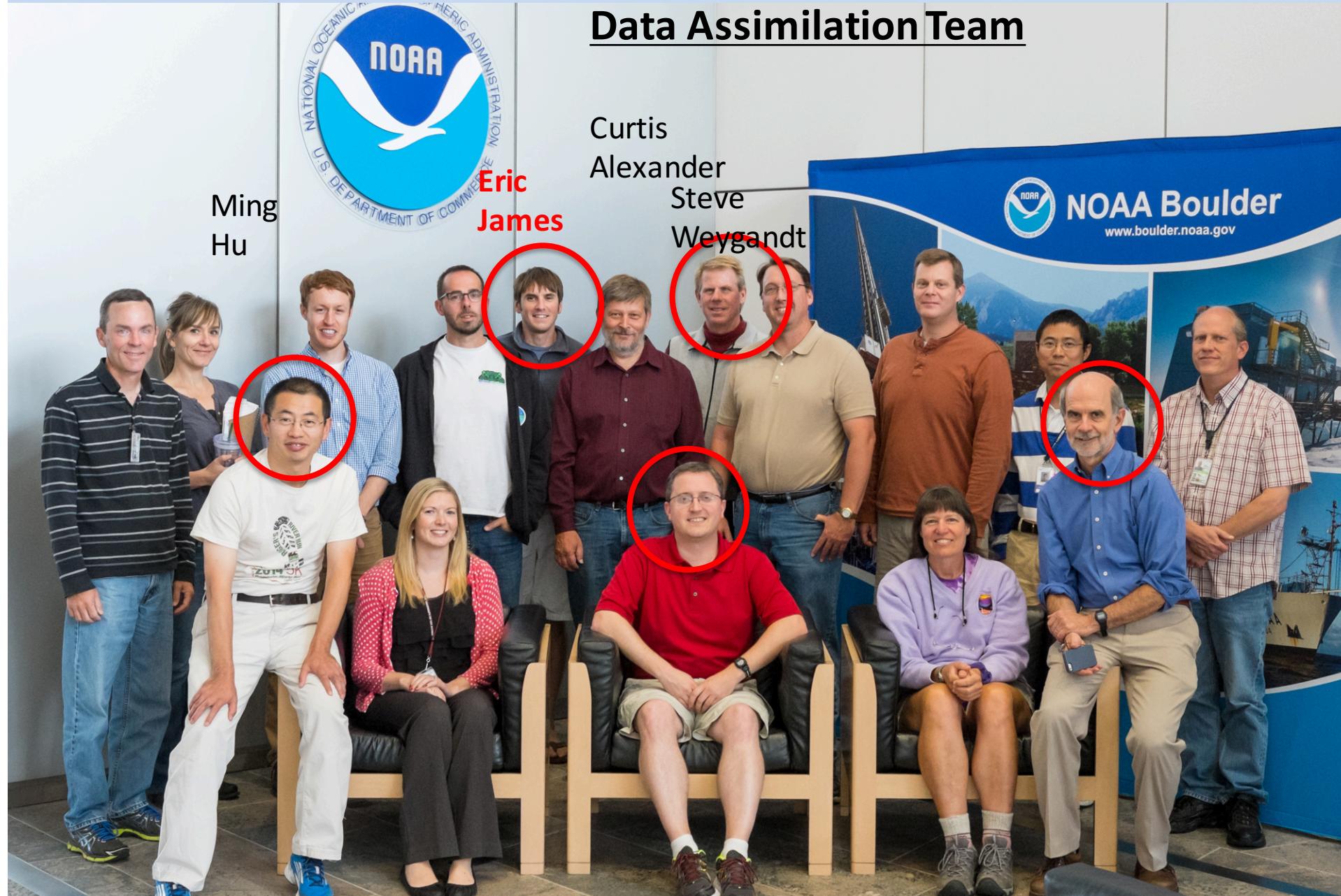
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*NOAA Earth System Research Laboratory  
Global Systems Division  
Earth Modeling Branch  
Boulder, Colorado USA*

RAP model/assimilation description/results  
2016, Mon. Wea. Rev., Benjamin et al.

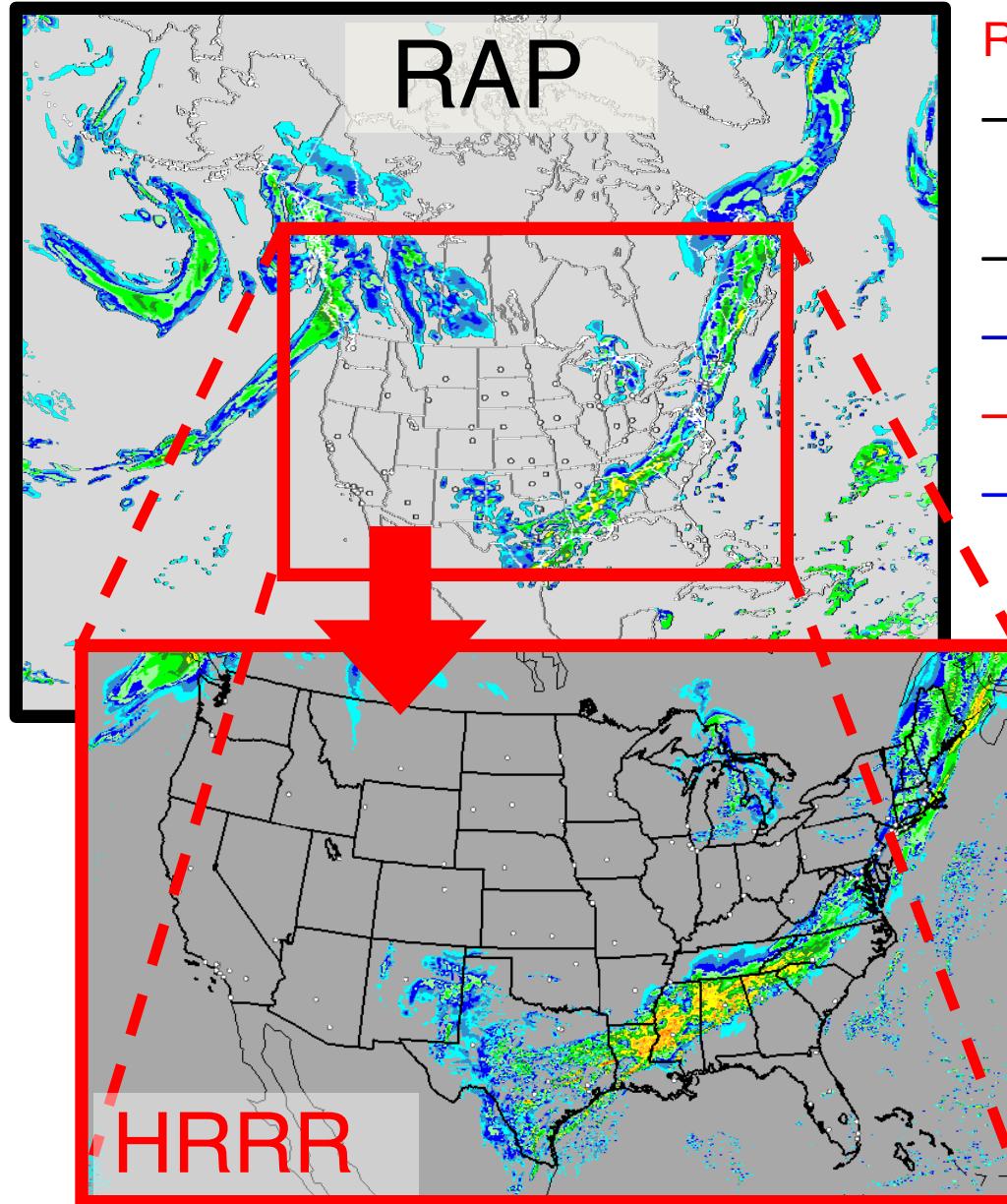
**AMS IOAS – New Orleans  
13 Jan 2016**

# ESRL/GSD HRRR/RAP Development Team





# Current Status - NOAA Hourly Updated Models



## RAP - Rapid Refresh

- NOAA “situational awareness” model for high-impact weather
- New 18-hour forecast each hour
- NOAA/NCEP operational – 1 May 2012
- RAPv2 implementation – 25 Feb 2014
- Hourly use by National Weather Service, SPC/AWC/WPC, FAA, private sector

## HRRR – High-Resolution Rapid Refresh

- Storm/energy/aviation guidance
- Real-time operational – NCEP, and *experimental* - ESRL supercomputer
- NCEP implementation HRRRv1 - 30 September 2014
- **HRRRv2/RAPv3 – est. May 2016**

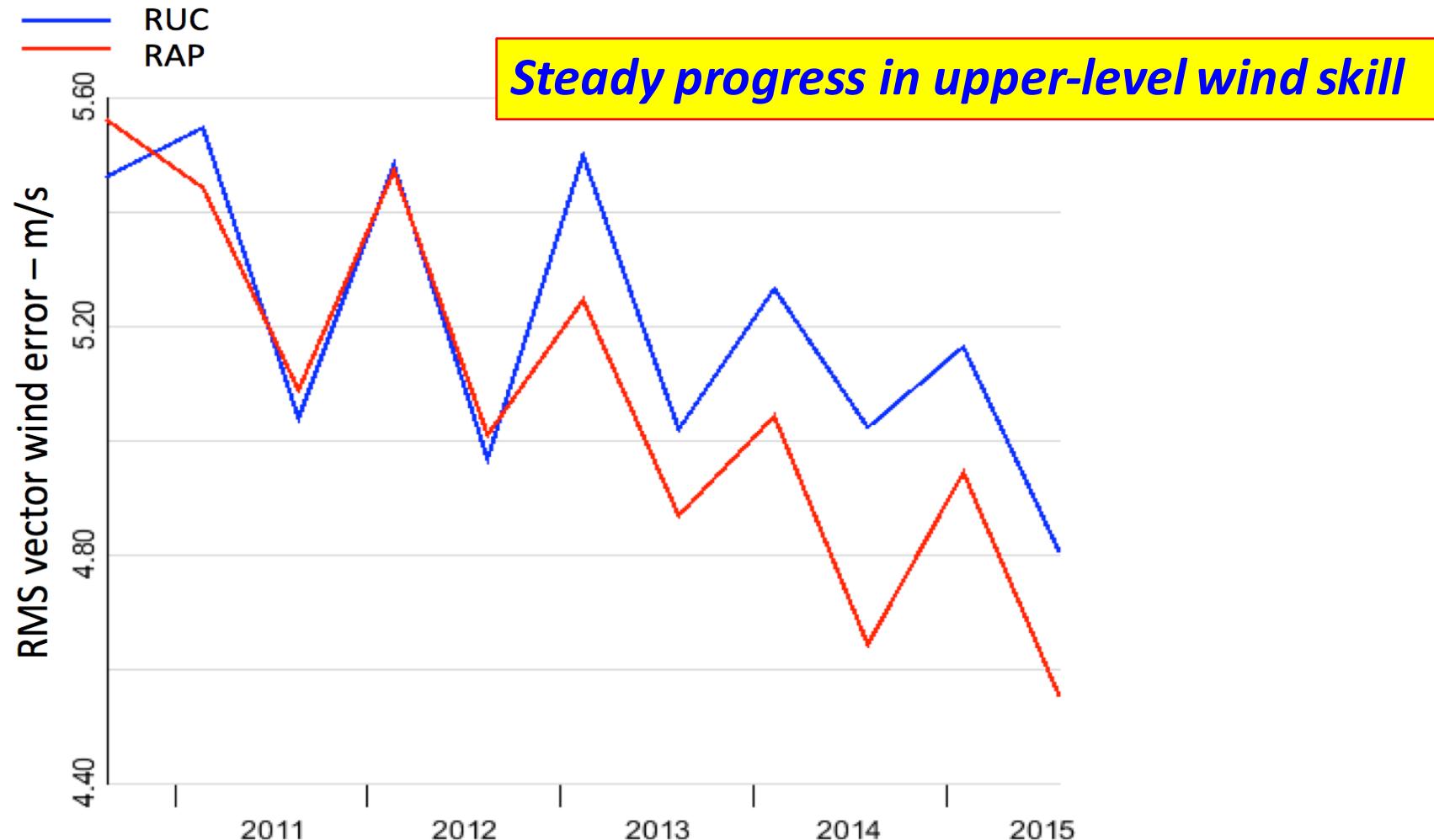
# RAP vs. RUC - hourly updated NWP models at NOAA

| Model  | Domain  | Grid Points                     | Grid Spacing   | Vertical Levels                 | Vertical Coordinate  | Pressure Top         | Lateral Boundary Conditions |               |          |
|--------|---|---------------------------------|----------------|---------------------------------|----------------------|----------------------|-----------------------------|---------------|----------|
| RUC    | CONUS   | 451 x 337                       | 13 km          | 50                              | Sigma/<br>Isentropic | ~50 hPa              | NAM                         |               |          |
| RAP    | North America                                       | 758 x 567                       | 13 km          | 51                              | Sigma                | 10 hPa               | GFS                         |               |          |
| RAPv3  | Enlarged North America                              | 954 X 835                       | 13 km          | 51                              | Sigma                | 10 hPa               | GFS                         |               |          |
| Model  | Assimilation  | DFI                             | Cloud Analysis | Micro-physics                   | WRF version          | Radiation LW/SW      | Cumulus param               | PBL           | LSM      |
| RUC    | RUC-3DVAR   | Yes w/radar                     | Yes            | Thompson et al (2004)           | N/A                  | RRTM/Dudhia          | Grell-Devenyi               | Burk-Thompson | RUC 2003 |
| RAP    | GSI 3DVAR w/ radiances                              | Yes w/radar reflectivity        | Yes            | Thompson (2008) w/ enhancements | V3.2.1+              | RRTM/Goddard         | Grell-3d                    | MYJ           | RUC 2010 |
| RAP v2 | GSI with hybrid ensemble/var (0.5/0.5) assimilation | Yes w/ radar refl               | Yes            | Ditto, w/ minor adjustments     | V3.4.1+              | RRTM/Goddard         | Grell-3d                    | MYNN          | RUC 2014 |
| RAP v3 | GSI-hybrid ens/var (0.75/0.25) assimilation         | Yes w/ radar refl and lightning | Yes            | Thompson and Eidhammer (2014)   | V3.6.1+<br>RRTMG     | Grell-Freitas (2014) | MYNN                        |               | RUC 2015 |

# 250 hPa RMS vector error vs. raobs over CONUS

## RUC / RAP

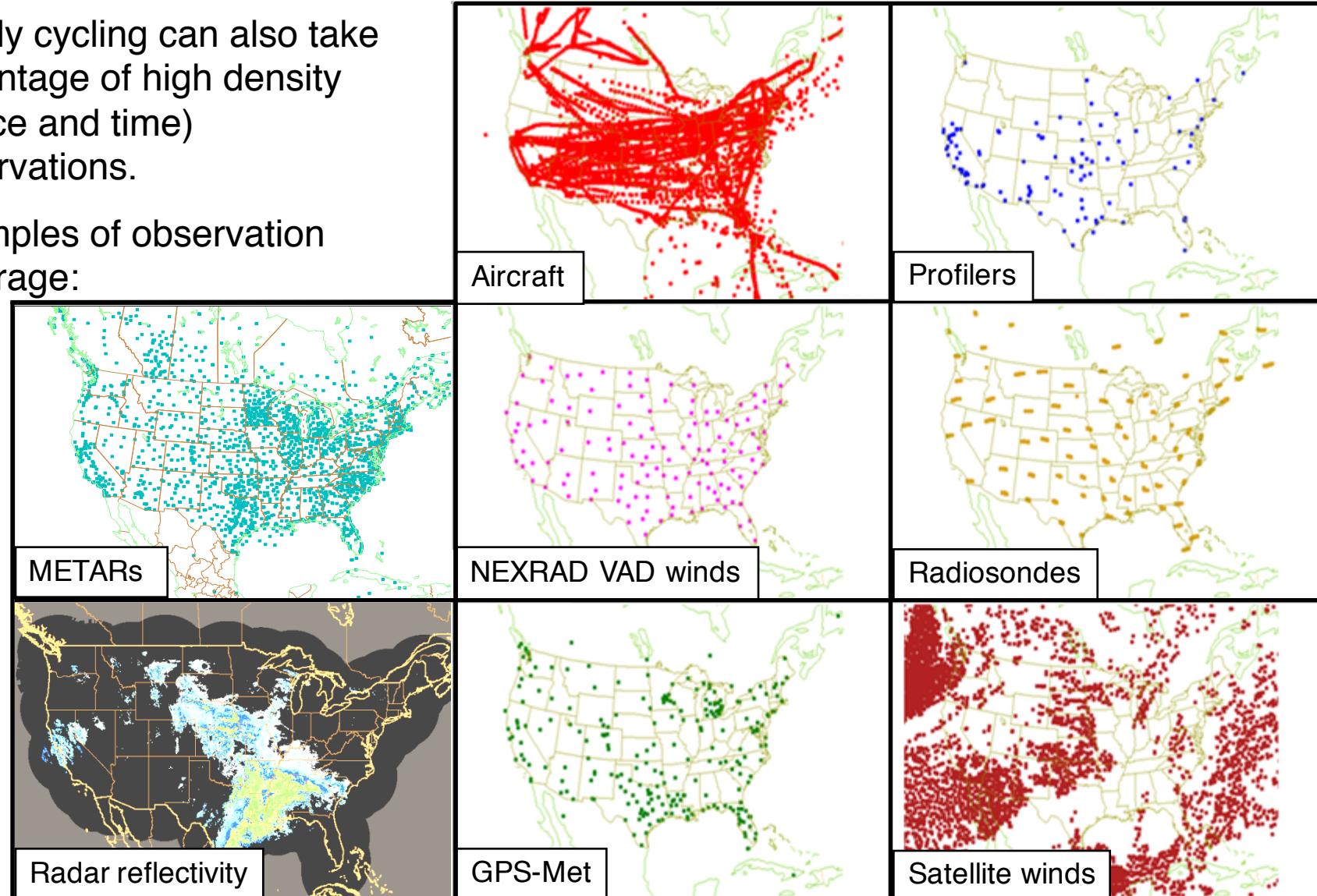
### 2010-2015 – 6h forecasts



# Why do the HRRR and the RAP use hourly updates?

Hourly cycling can also take advantage of high density (space and time) observations.

Examples of observation coverage:



# RAPv3: Observations used (new 2015-ESRL)

**HRRV2** – all except radiances into 3km GSI assimilation

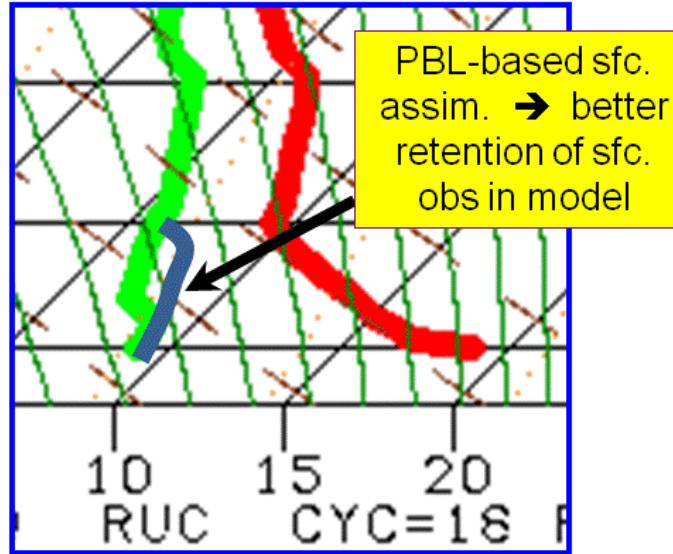
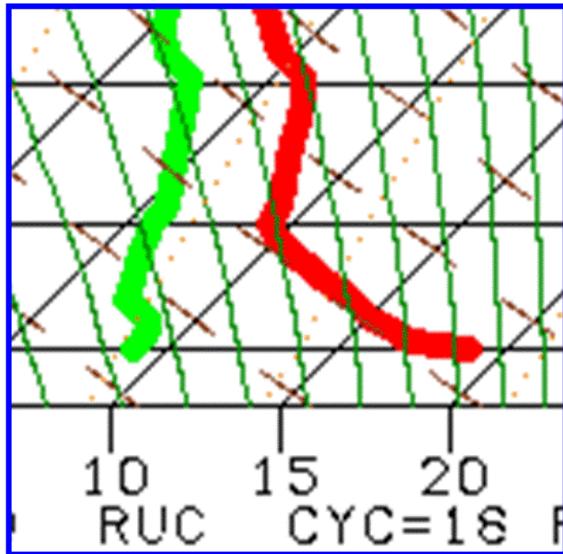
| Hourly Observation Type    | Variables Observed   | Observation Count |
|----------------------------|--|-------------------|
| Rawinsonde                 | Temperature, Humidity, Wind, Pressure                              | 120               |
| Profiler – 915 MHz         | Wind, Virtual Temperature  | 20-30             |
| Radar – VAD                | Wind   | 125               |
| Radar                      | <b>Radial Velocity</b>   | <b>125 radars</b> |
| Radar reflectivity – CONUS | 3-d refl → Rain, Snow, Graupel                                     | 1,500,000         |
| Lightning                  | (proxy reflectivity)   | NLDN              |
| Aircraft                   | Wind, Temperature  | 2,000 -15,000     |
| Aircraft - WVSS            | Humidity   | 0 - 800           |
| Surface/METAR              | Temperature, Moisture, Wind, Pressure, Clouds, Visibility, Weather | 2200 - 2500       |
| Surface/Mesonet            | <b>Temperature, Moisture, Wind</b>                                 | <b>~5K-12K</b>    |
| Buoys/ships                | Wind, Pressure   | 200 - 400         |
| GOES AMVs                  | Wind   | 2000 - 4000       |
| AMSU/HIRS/MHS (RARS)       | Radiances  | 1K-10K            |
| GOES                       | <b>Radiances</b>   | <b>large</b>      |
| GOES cloud-top press/temp  | Cloud Top Height   | 100,000           |
| GPS – Precipitable water   | Humidity   | 260               |
| WindSat Scatterometer      | Winds  | 2,000 – 10,000    |



# Rapid Refresh/HRRR GSI Options – Surface Obs

## Special treatments for surface observations

### PBL-based pseudo-observations

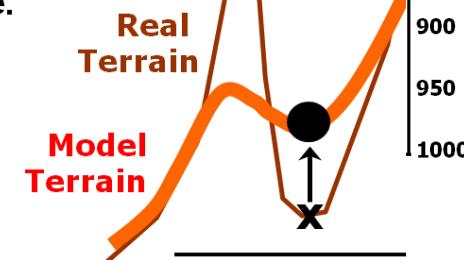


### Elevation correction

If  $\text{abs}[\text{Psfc}(\text{obs-model})] < 70 \text{ hPa}$ .

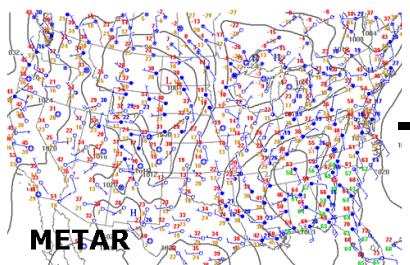
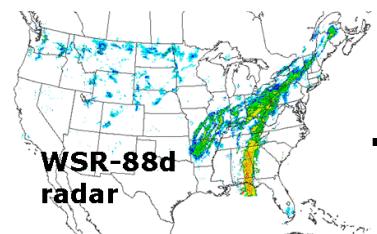
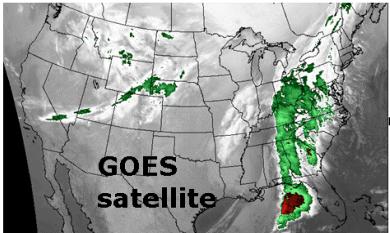
Extrapolate obs from  $\text{Psfc}_{\text{obs}}$  to  $\text{Psfc}_{\text{model}}$

Use model 1h low-level lapse rate.

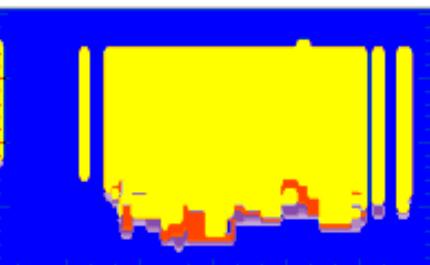
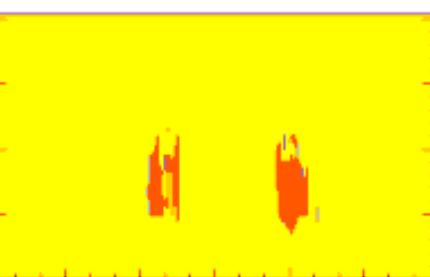
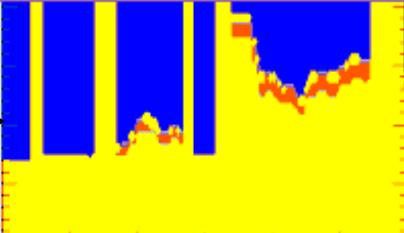


# What is the GSI cloud and precipitation hydrometeor analysis used in HRRR/RAP?

Observations

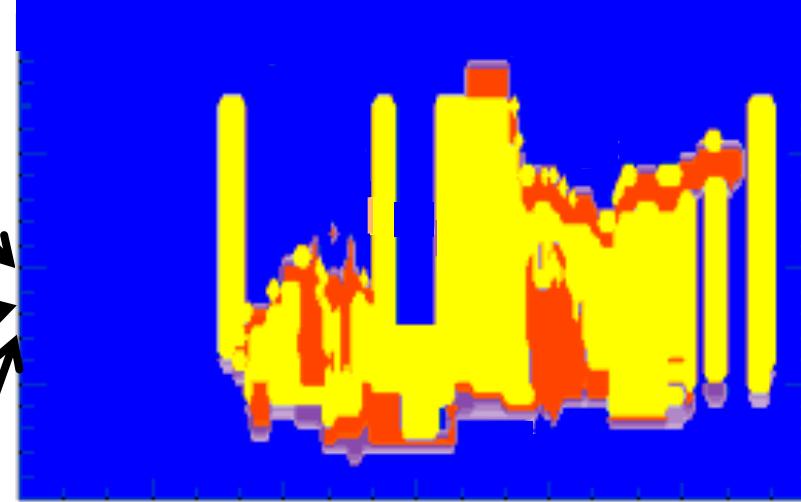


Map to cloud field

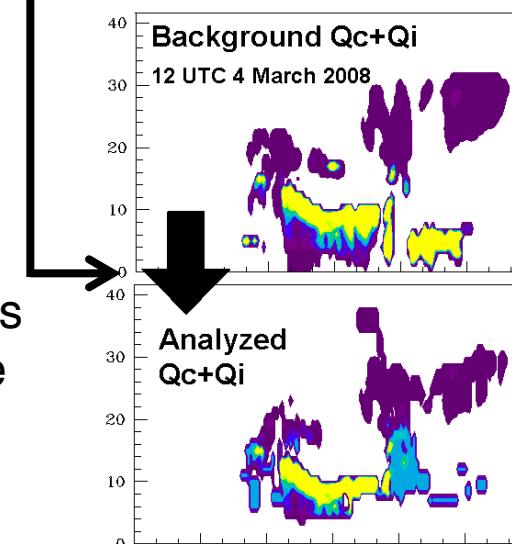


Legend:  
No cloud (Blue)  
Cloud (Red)  
Unknown (Yellow)

Merge cloud field



Update  
hydrometeors  
based on the  
cloud field



# Topic of this presentation:

## Regional observation denial experiments with NOAA hourly assimilation cycles

- Rapid Refresh – version 2 (not v3)
  - Improved data assimilation using ensemble-hybrid assimilation that extracts more information from observations
  - 8 days during late spring season (May 2013)

| Model  | Assimilation   | DFI                             | Cloud Analysis | Micro-physics                   | WRF version | Radiation LW/SW | Cumulus parm         | PBL           | LSM      |
|--------|--|---------------------------------|----------------|---------------------------------|-------------|-----------------|----------------------|---------------|----------|
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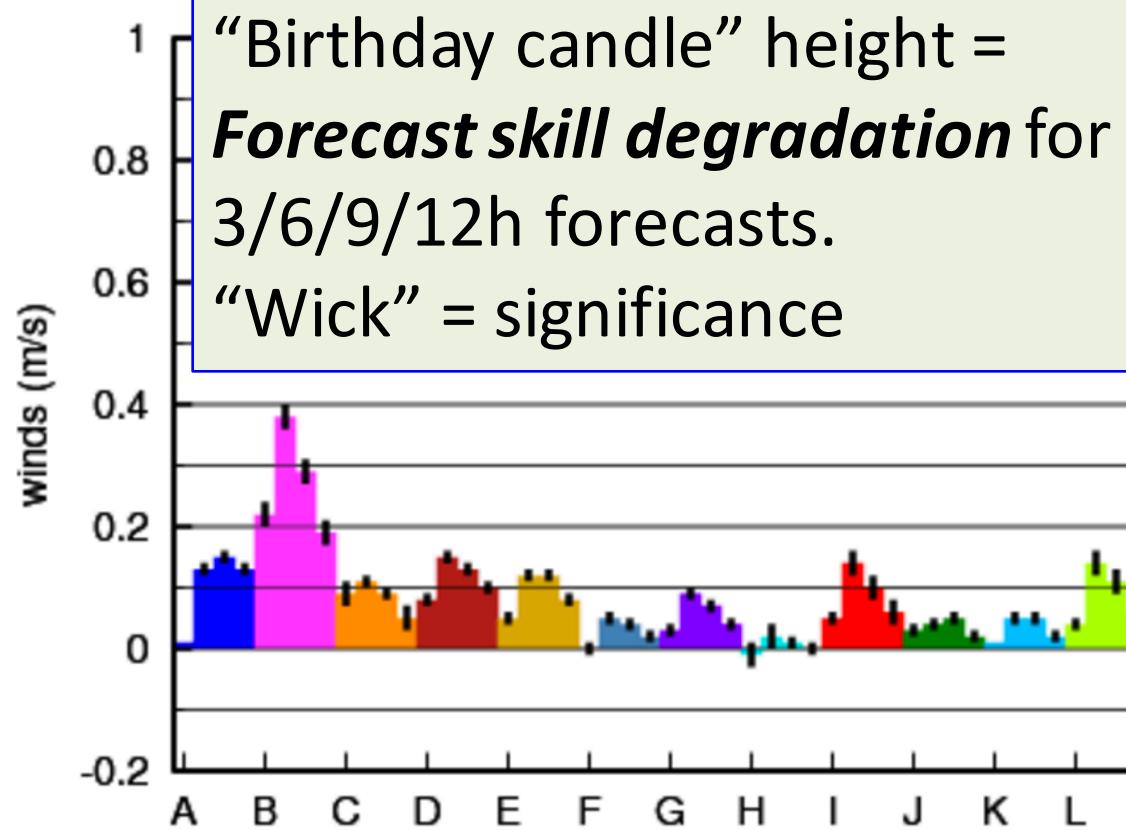
# RAP observation denial experiments

- A - withhold rawinsonde obs - Exp. raob - control
- B - withhold aircraft obs - Exp. aircraft - control
- C - withhold aircraft obs above 350 hPa - Exp. aircraft ABOVE350 - control
- D - withhold aircraft obs below 350 hPa - Exp. aircraft BELOW350 - control
- E - withhold aircraft temp/humidity obs - Exp. aircrafttempRH - control
- F - withhold profiler obs - Exp. profiler - control
- G - withhold radar reflectivity - Exp. radar - control
- H - withhold VAD winds - Exp. vad - control
- I - withhold surface obs including METAR cloud - Exp. surface - control
- J - withhold GPS-Met precipitable water obs - Exp. gpsmet - control
- K - withhold AMVs - Exp. clouddrift - control
- L - withhold GOES satellite obs - Exp. goes - control

## Experiments

- Aircraft related
  - B – withhold all aircraft
  - C – withhold only a/c < 350 hPa
  - D – withhold only a/c > 350 hPa
  - E – withhold a/c temp/humidity
- Radar related
  - G – withhold radar reflectivity
  - H – withhold VAD winds
- Satellite related
  - K – withhold AMVs (winds) only
  - L – withhold all GOES (wind/cld)

RR region, winds averaged rms - matched  
2013-05-16 thru 2013-05-23 (1000-100 mb)  
Forecasts valid at 00 and 12 UTC



"Birthday candle" height =  
***Forecast skill degradation*** for  
3/6/9/12h forecasts.  
"Wick" = significance

**Wind forecast impact**  
**1000-100 hPa**

## Diurnal dependencies for observations

- Aircraft
  - minimum in commercial traffic at night (06z-11z) over N. America
- Profiler, VAD winds –
  - vulnerable to bird migration contamination at night in spring/fall
- Surface –
  - Winds/temperature/dewpoint obs representative over deeper boundary layer in daytime

## Breakdown for RAP OSE results

- 13 experiments (control, 12 obs denial experiments)
- 2 regions
  - US National (data rich)
  - N. American domain (full RAP domain, broader geographical variation)
- 4 layers
  - 1000-100 hPa (full depth)
  - 1000-800 hPa (~boundary-layer, near surface)
  - 800-400 hPa (mid-troposphere)
  - 400-100 hPa (upper troposphere, lower stratosphere)
- Forecast duration
  - 3h, 6h, 9h, 12h
- Valid time of day
  - 00z, 12z
  - Combined

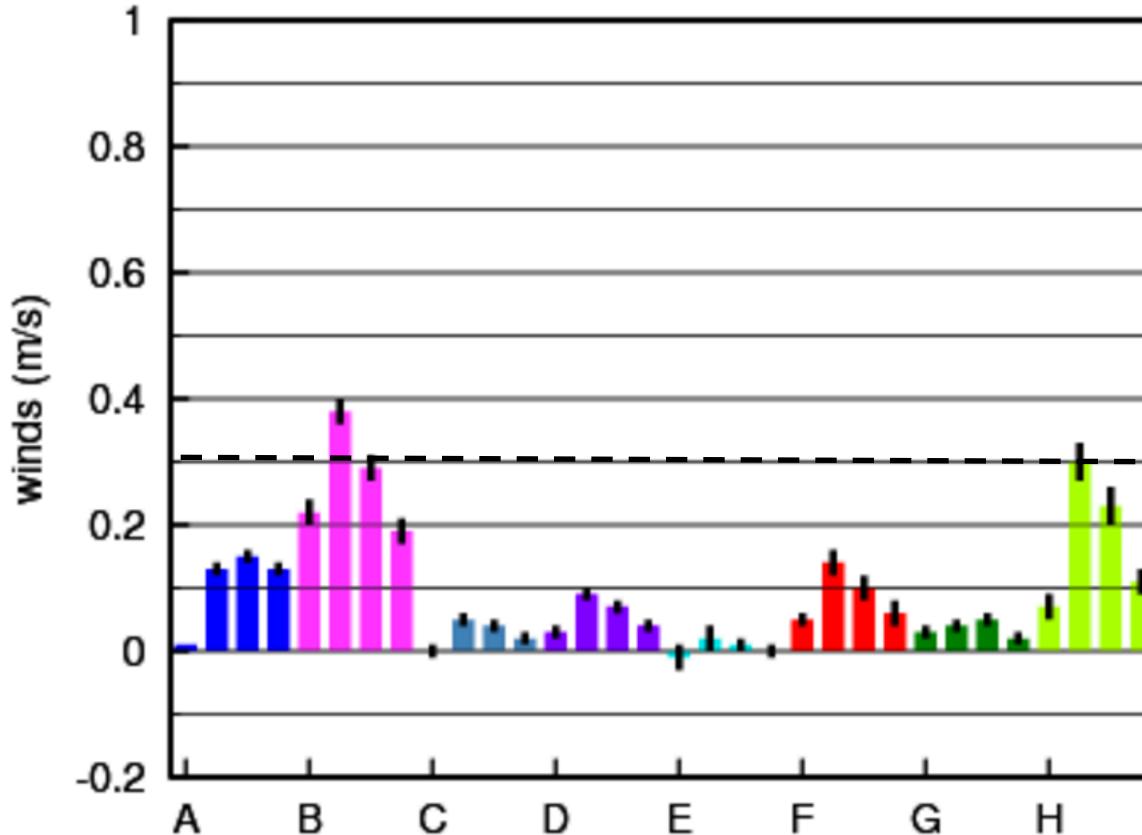
5 dimensions!  
Q: HOW TO SUMMARIZE?  
A: Composite plots

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# N.Am. domain, 3h/6h/9h/12h, 12z+00z



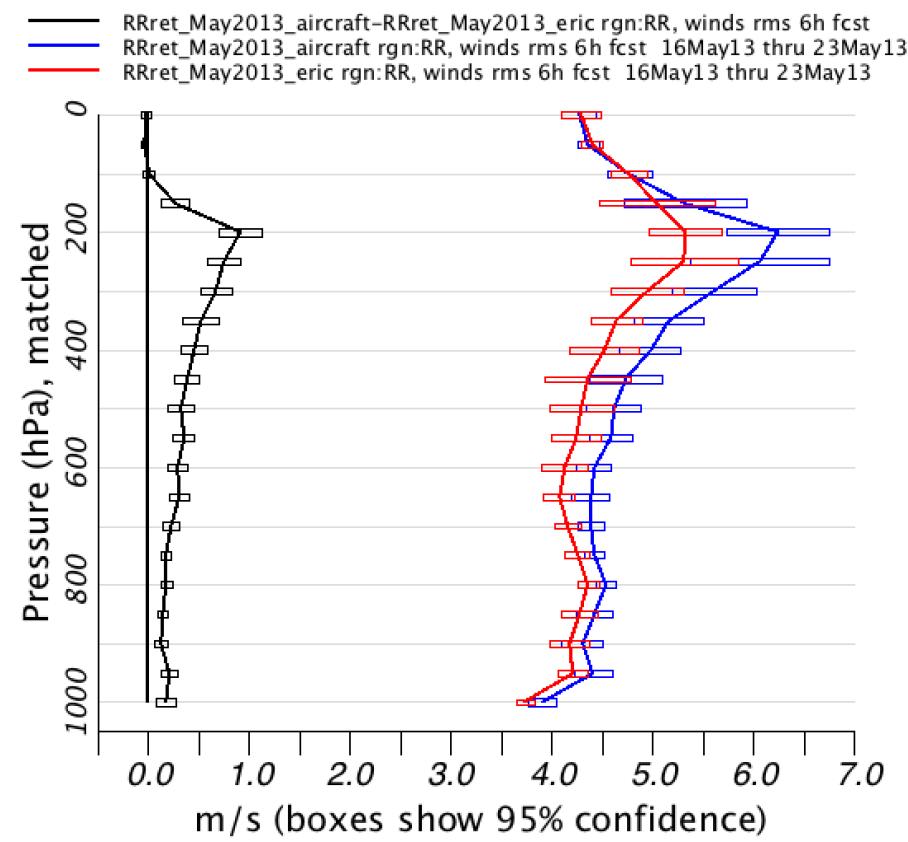
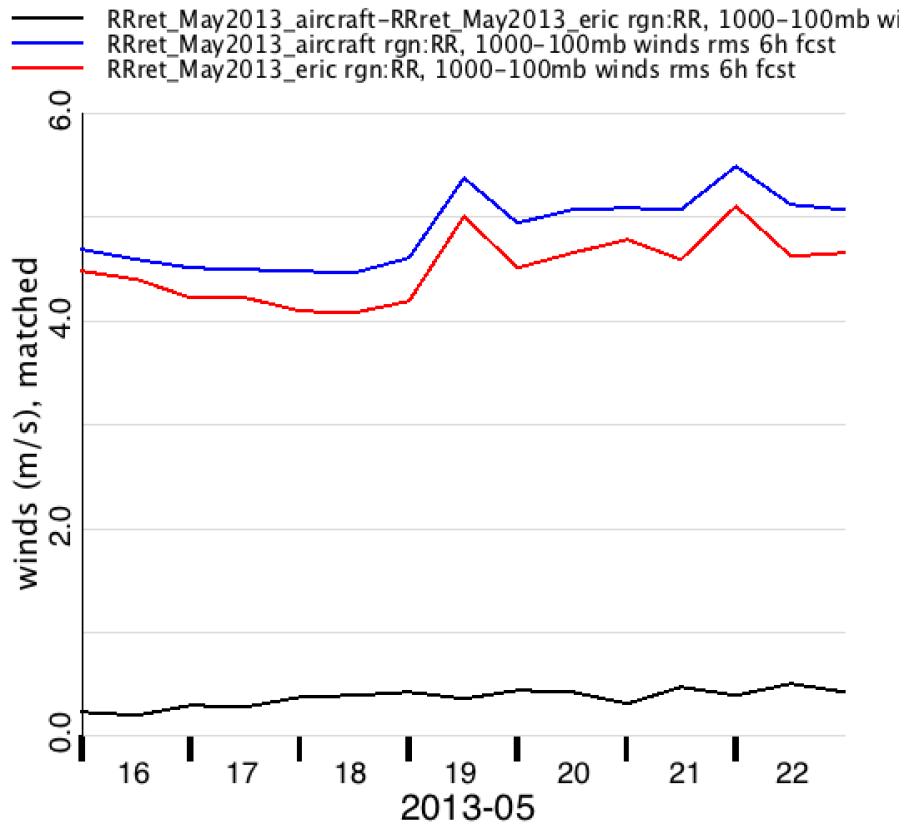
**Wind 1000-100 hPa**  
Aircraft #1,  
#2 GOES

-20% Error reduction

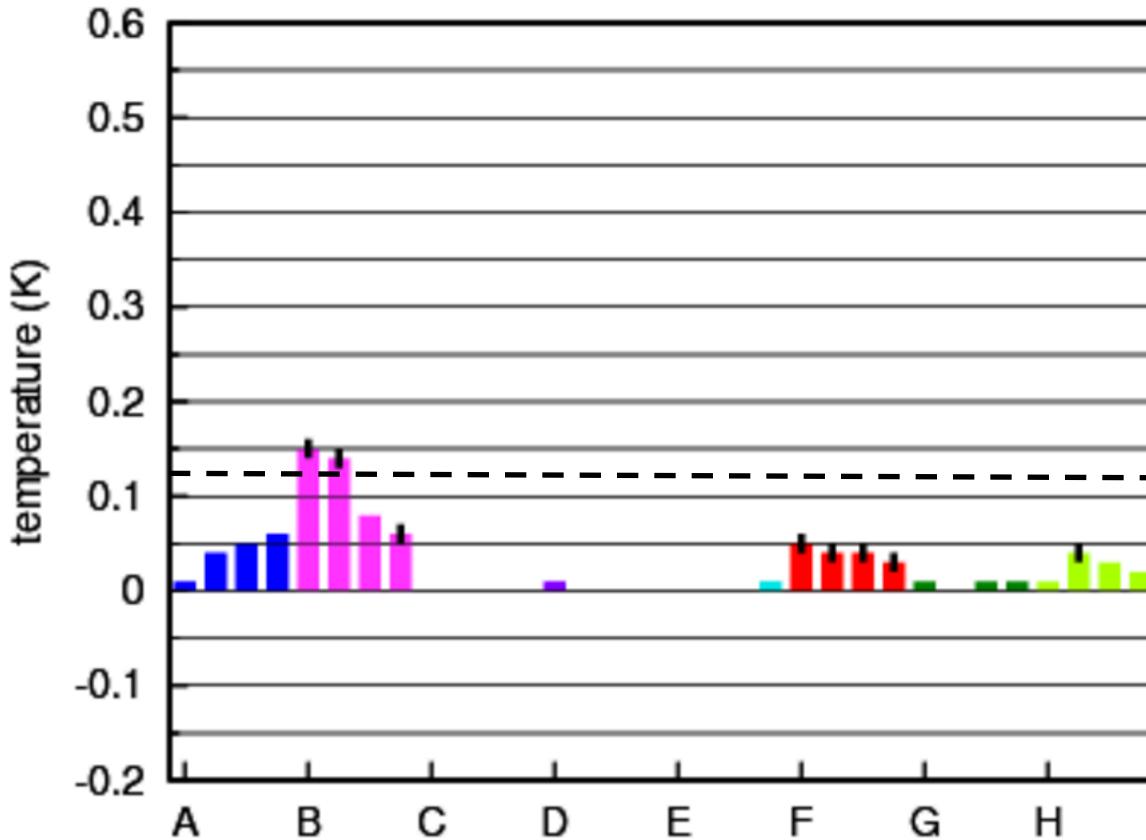
**6h F – 0h A for  
normalizing**  
**V – 1.5 m/s, T – 0.6K**  
**RH – 5%**

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- █ E - withhold VAD winds - Exp. vad - control
- █ F - withhold surface obs including METAR cloud - Exp. surface - control
- █ G - withhold GPS-Met precipitable water obs - Exp. gpsmet - control
- █ H - withhold GOES satellite obs - Exp. goes - control

# Checkout of 6h aircraft forecast impact for temporal and vertical consistency



# N.Am. domain, 3h/6h/9h/12h, 12z+00z



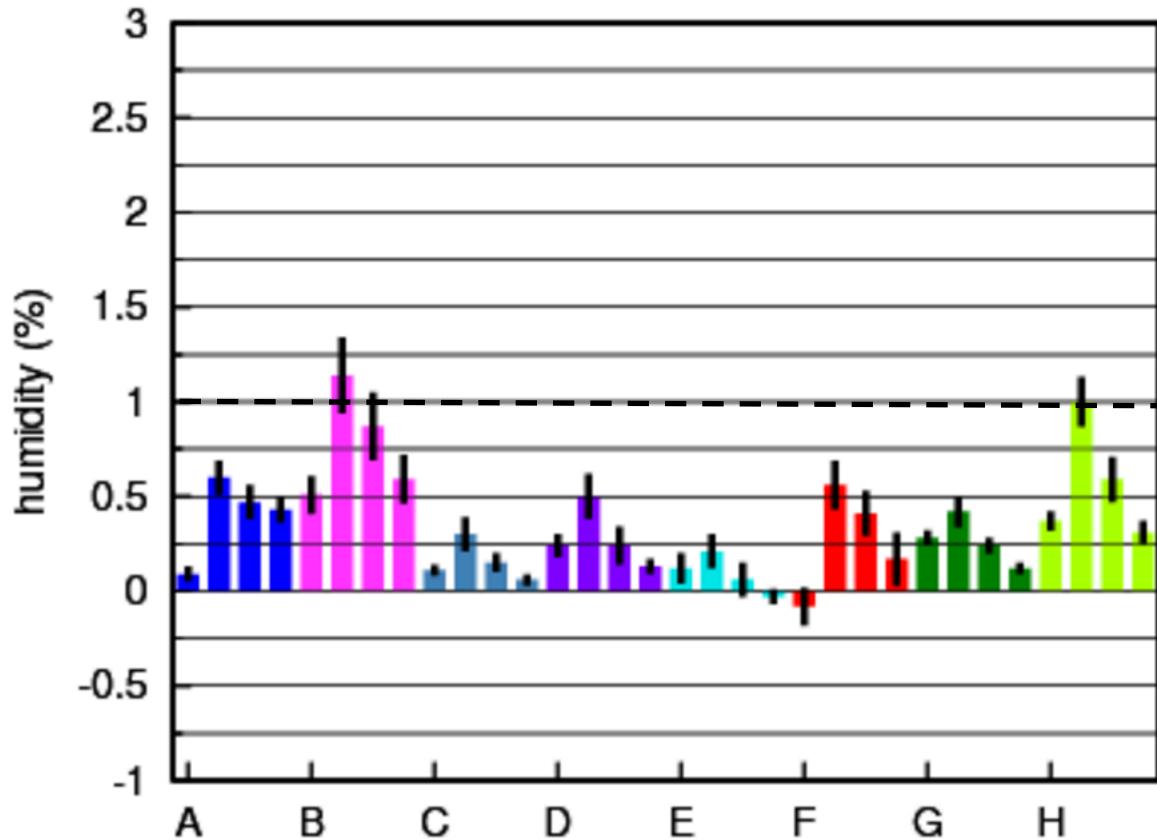
**Temp 1000-100 hPa**  
Aircraft #1,  
#2 sfc, raob

-20% Error reduction

**6h F – 0h A for**  
**normalizing**  
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# N.Am. domain, 3h/6h/9h/12h, 12z+00z



RH 1000-400 hPa

Aircraft #1,

#2 GOES

#3 Raobs

#4 Radar refl, GPS

-20% Error reduction

6h F – 0h A for

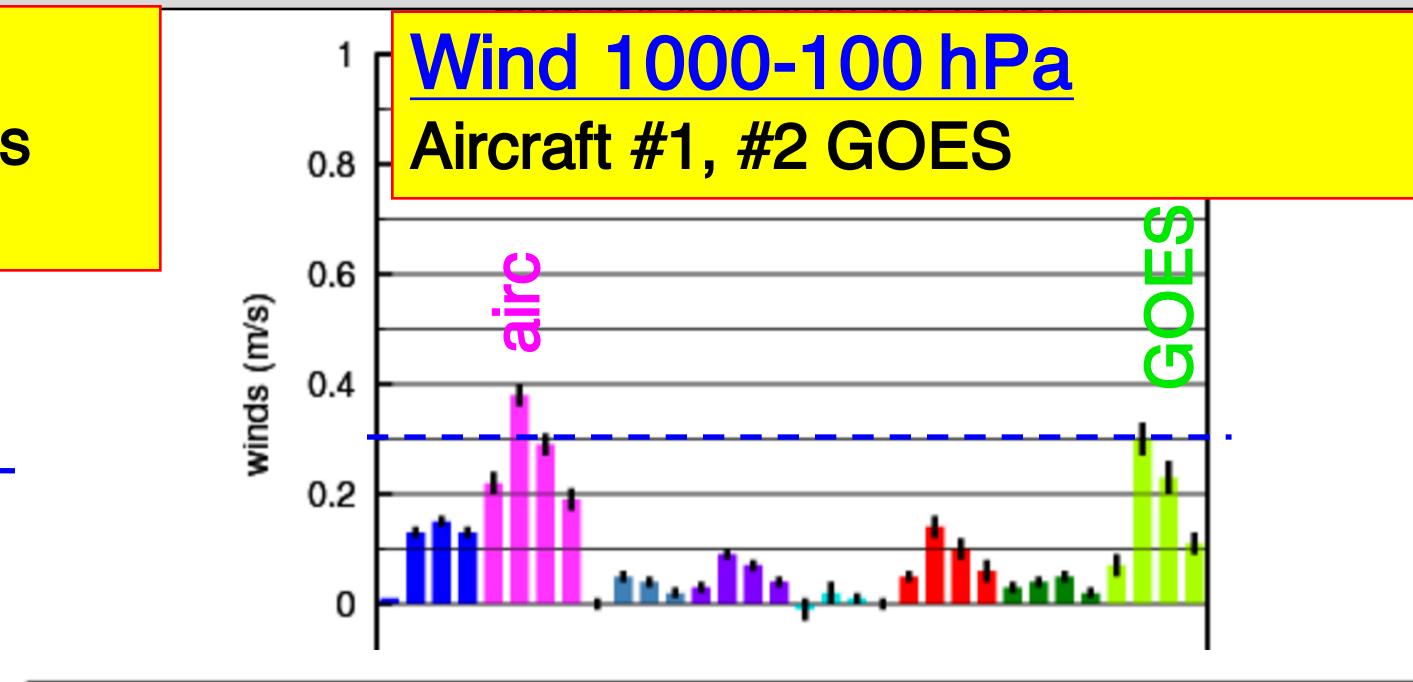
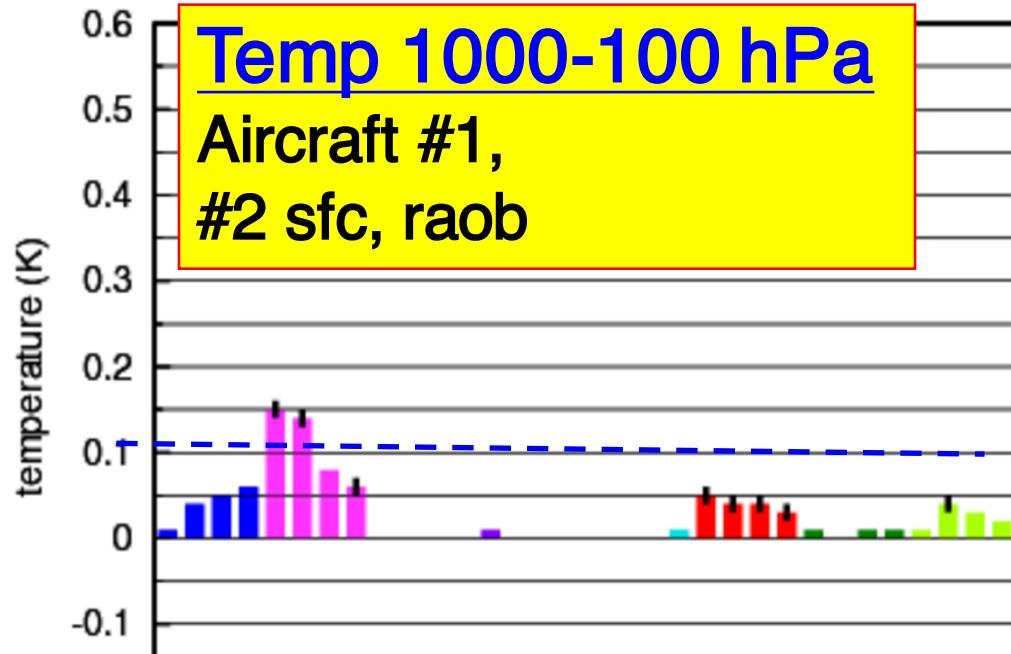
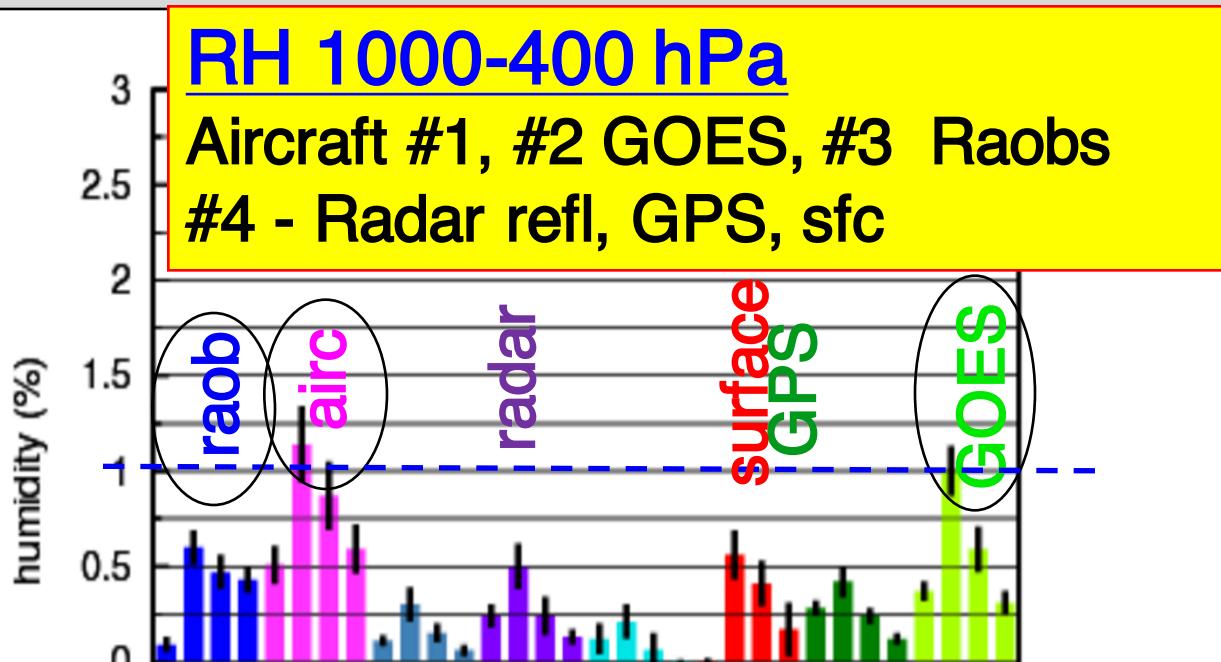
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# Summary - N. America, 3h/6h/9h/12h, 12z+00z, RAP



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6h F – 0h A for normalizing  
V – 1.5 m/s, T – 0.6K  
RH – 5%

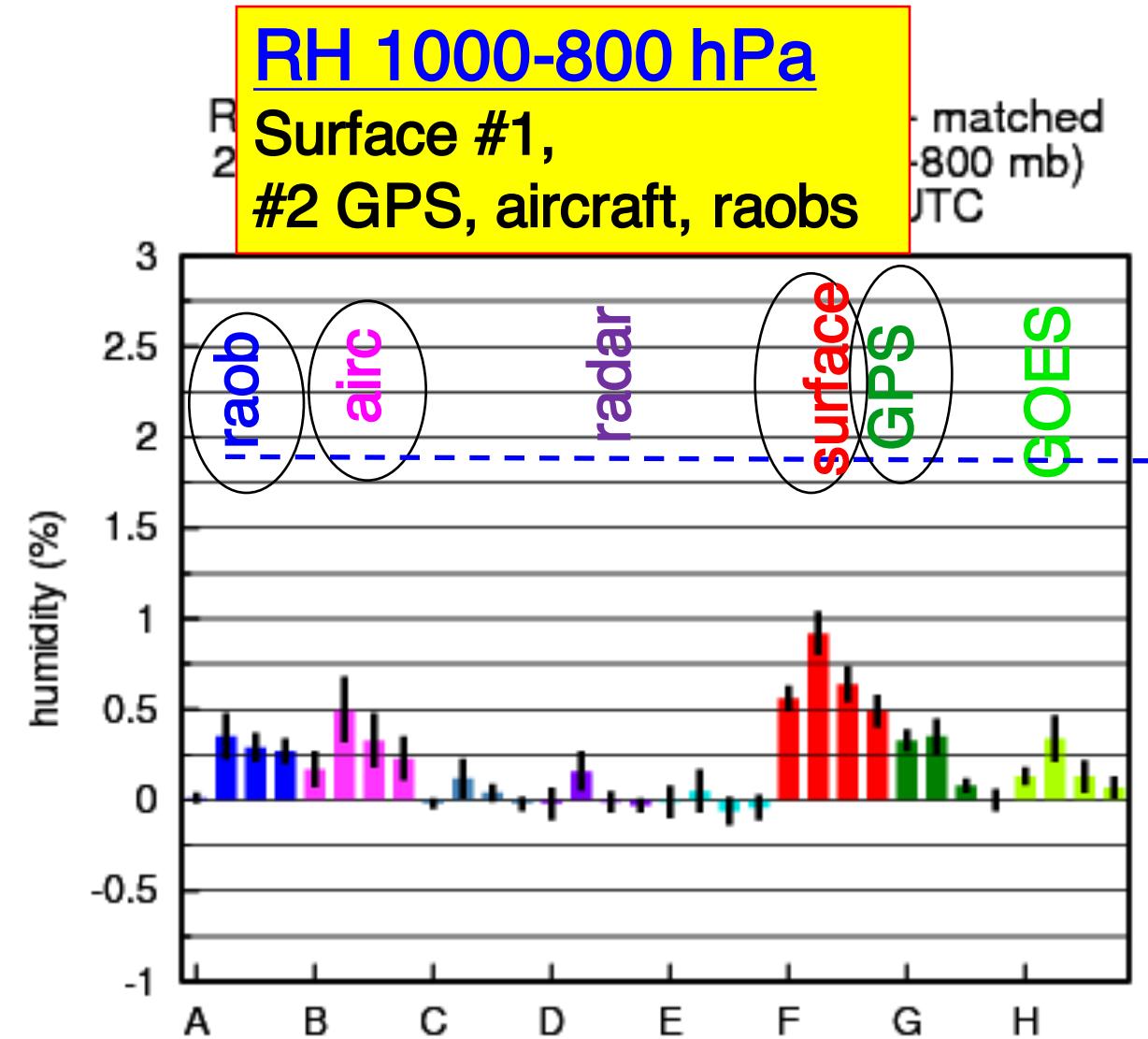
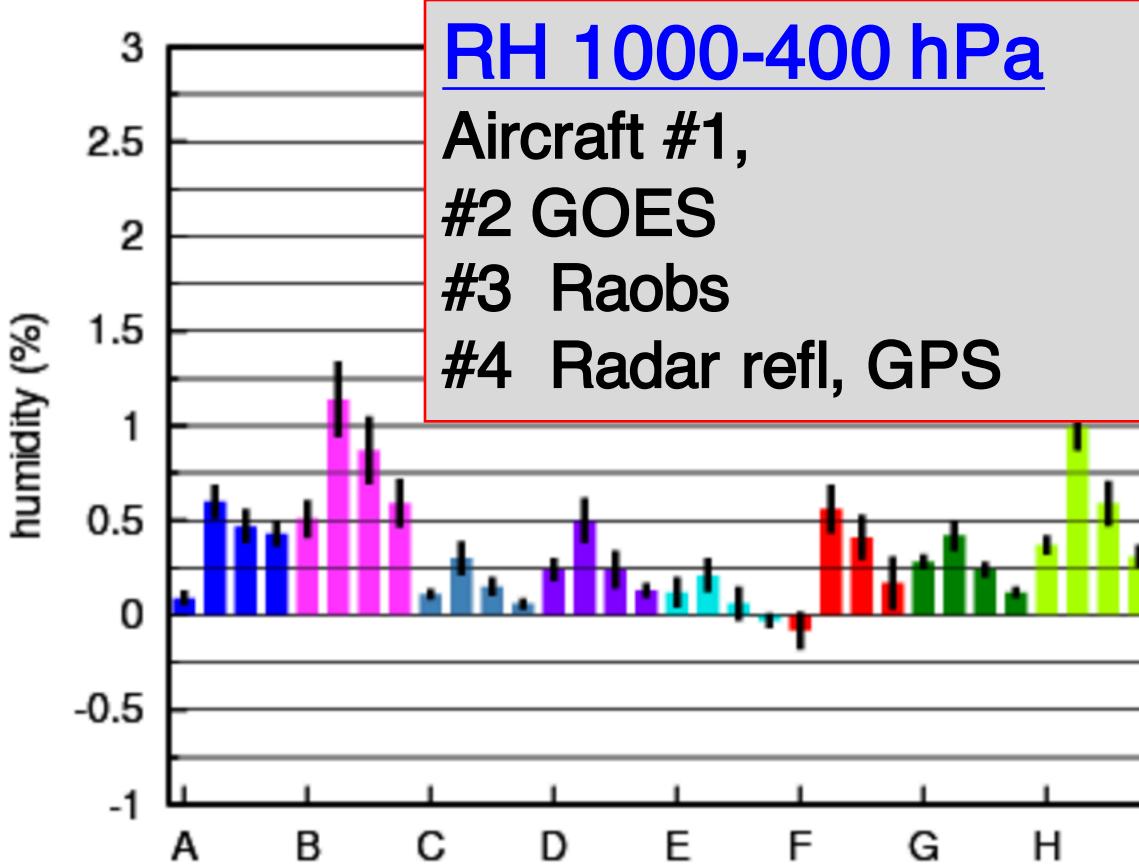
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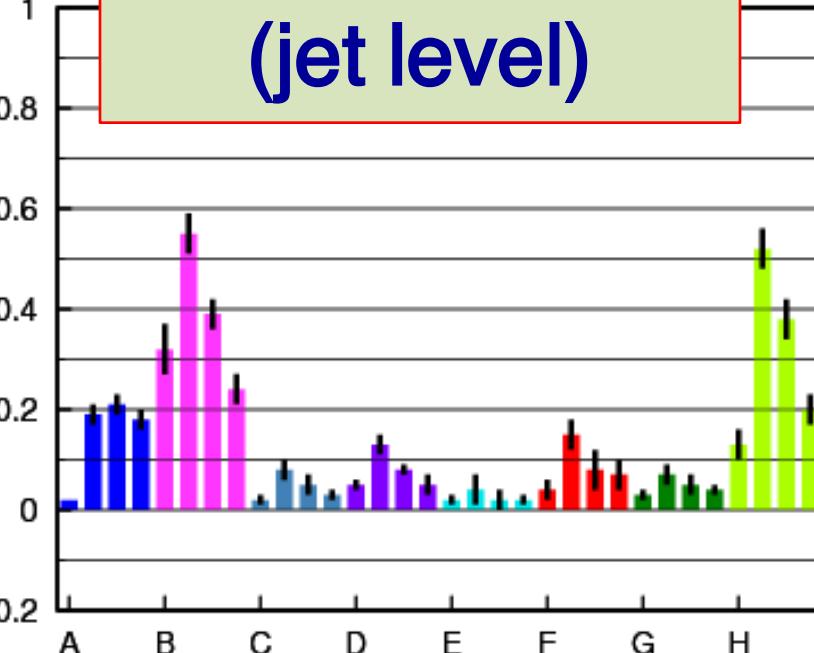
5 dimensions!  
Q: HOW TO SUMMARIZE?  
A: Composite plots

# Obs impact - RH in the boundary layer

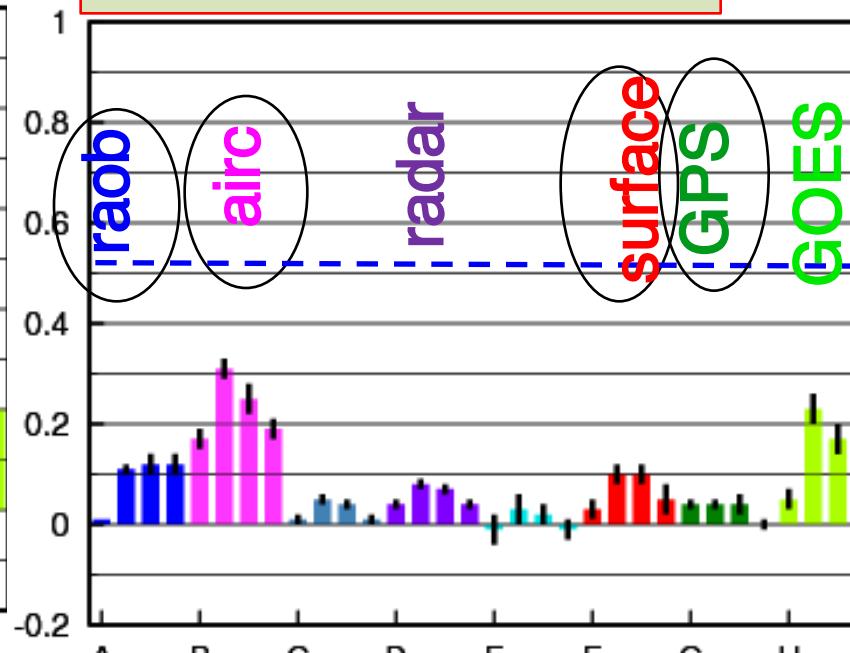
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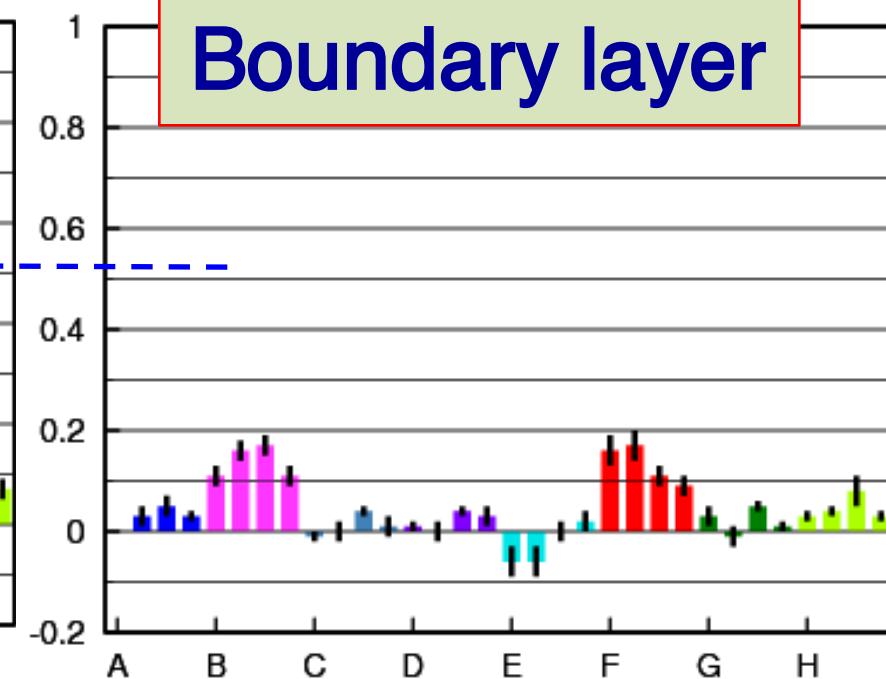
## 400-100 hPa (jet level)



## 800-400 hPa

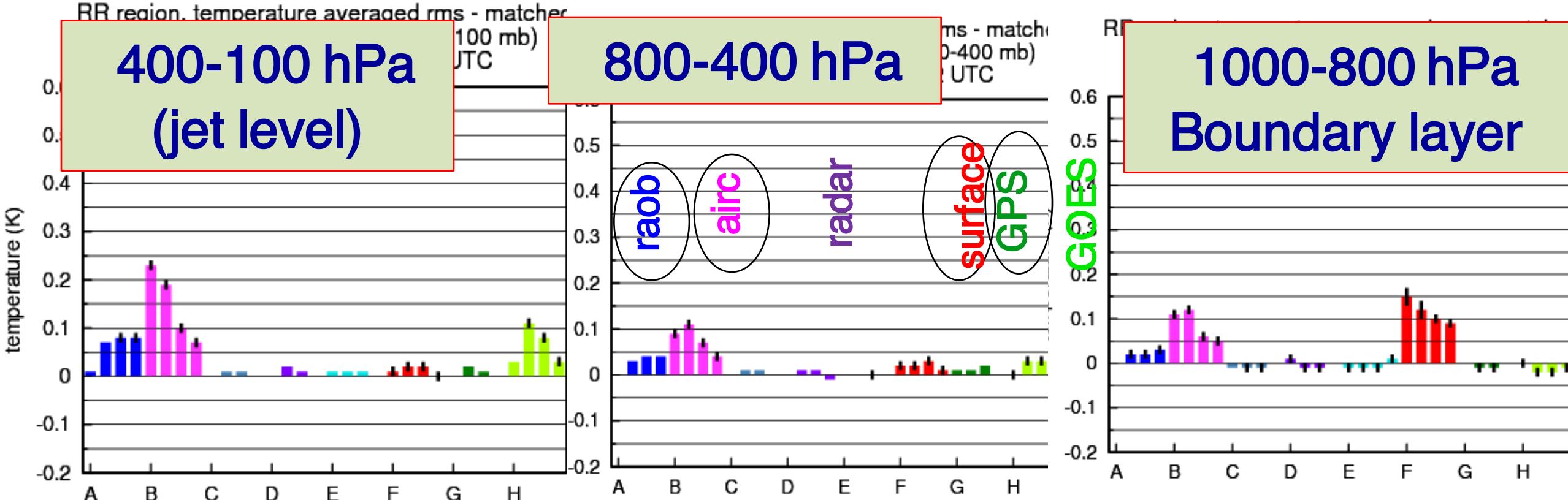


## 1000-800 hPa Boundary layer

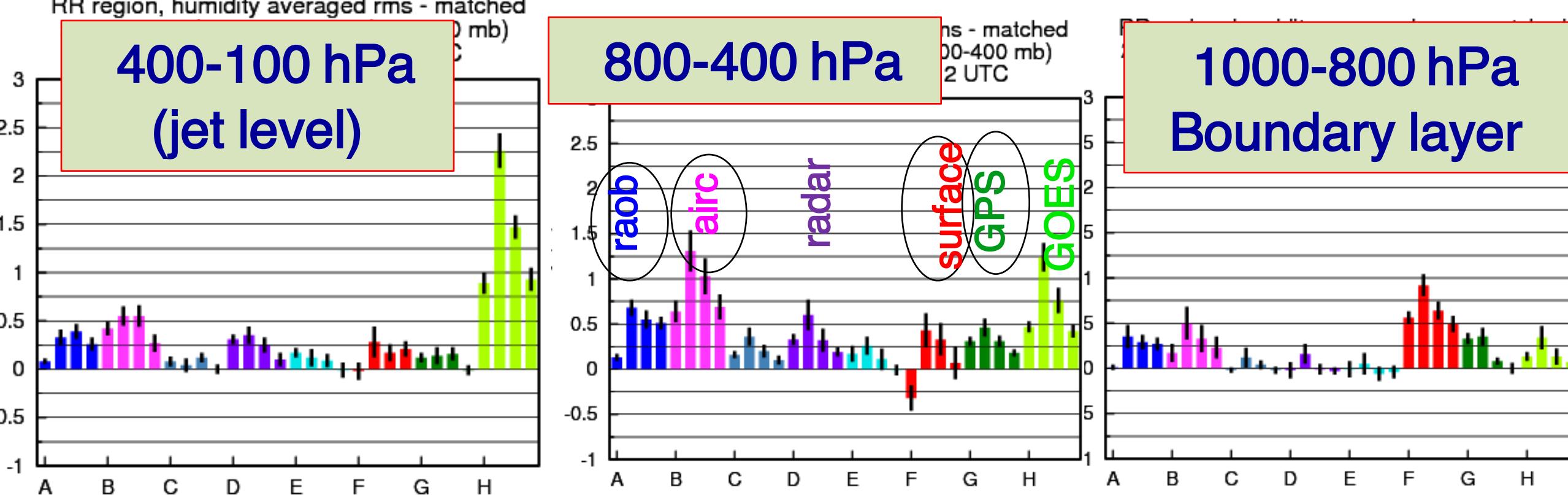


## Wind forecast obs impact by layers

- A - withhold rawinsonde obs - Exp. raob - control
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- C - withhold profiler obs - Exp. profiler - control
- D - withhold radar reflectivity - Exp. radar - control
- E - withhold VAD winds - Exp. vad - control
- F - withhold surface obs including METAR cloud - Exp. surface - control
- G - withhold GPS-Met precipitable water obs - Exp. gp
- H - withhold GOES satellite obs - Exp. goes - control



# Temperature forecast obs impact by layers

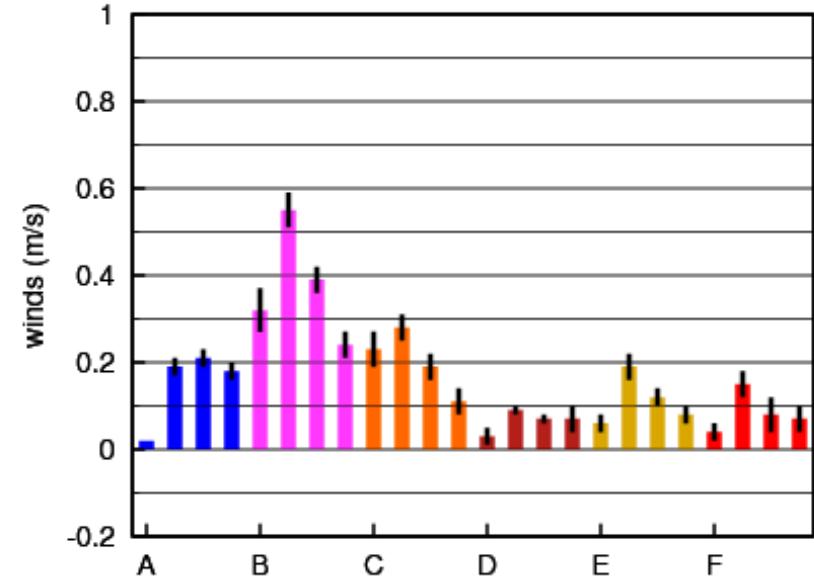


## RH forecast obs impact by layers

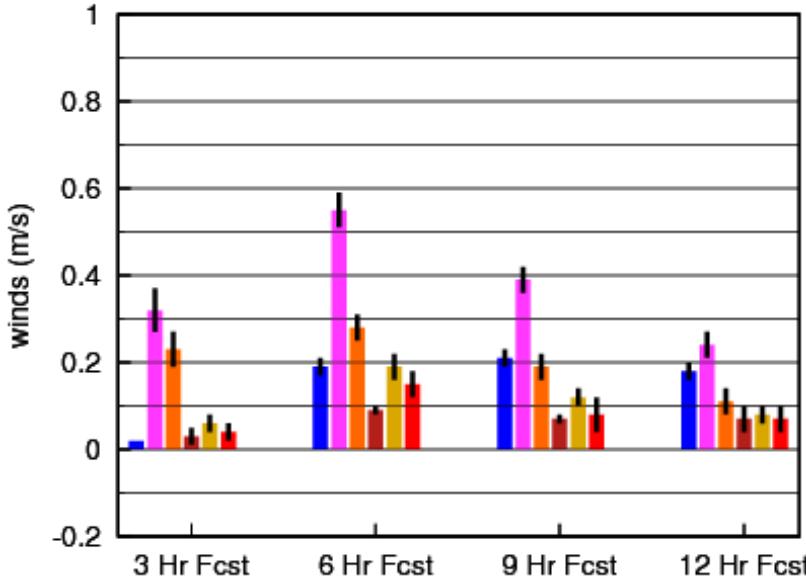
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- █ H - withhold GOES satellite obs - Exp. goes - control

# Aircraft obs impact – winds or temp/RH?

RR region, winds averaged rms - matched  
2013-05-16 thru 2013-05-23 (400-100 mb)  
Forecasts valid at 00 and 12 UTC



RR region, winds averaged rms - matched  
2013-05-16 thru 2013-05-23 (400-100 mb)  
Forecasts valid at 00 and 12 UTC



**For winds 400-100 hPa**

**For 3h forecasts,**

- most of aircraft impact from upper-level wind reports

**For 6/9/12h forecasts**

- Half of aircraft impact improvement is from ascent-descent reports
- Temp/RH reports

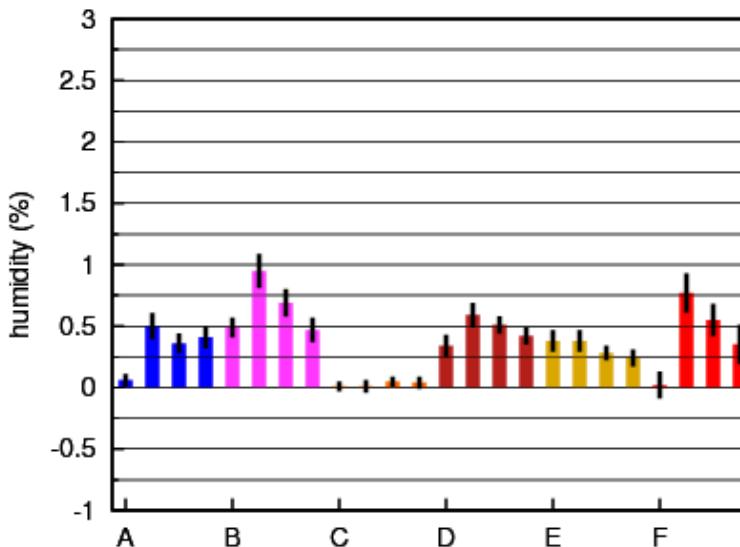
Legend:  
A - withhold rawinsonde obs - Exp. raob - control  
B - withhold aircraft obs - Exp. aircraft - control  
C - withhold aircraft obs above 350 hPa - Exp. aircraftABOVE350 - control  
D - withhold aircraft obs below 350 hPa - Exp. aircraftBELOW350 - control  
E - withhold aircraft temp/humidity obs - Exp. aircrafttempRH - control  
F - withhold surface obs including METAR cloud - Exp. surface - control

## Experiments

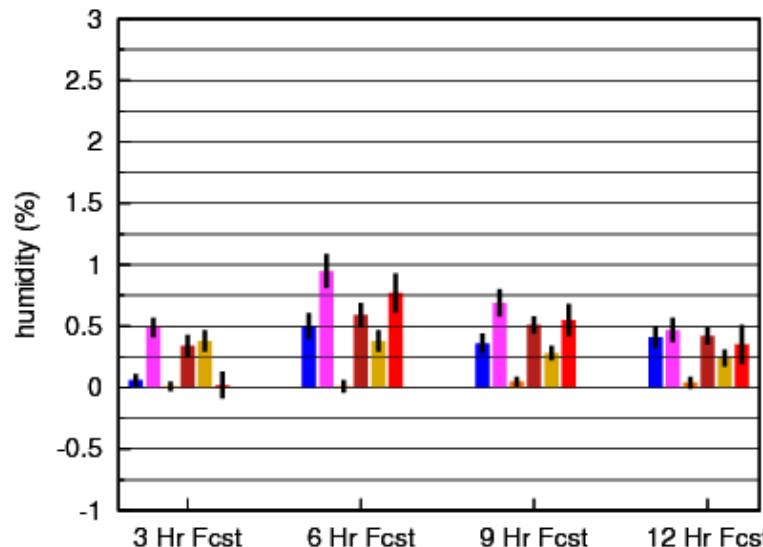
- Aircraft related
  - B – withhold all aircraft
  - C – withhold only a/c < 350 hPa
  - D – withhold only a/c > 350 hPa
  - E – withhold a/c temp/humidity

# Aircraft obs impact – winds or temp/RH?

RR region, humidity averaged rms - matched  
2013-05-16 thru 2013-05-23 (1000-600 mb)  
Forecasts valid at 00 and 12 UTC



RR region, humidity averaged rms - matched  
2013-05-16 thru 2013-05-23 (1000-600 mb)  
Forecasts valid at 00 and 12 UTC



## For RH 1000-600 hPa

For 3h forecasts,

- ~80% of aircraft impact from aircraft RH/temp obs

For 6/9h forecasts

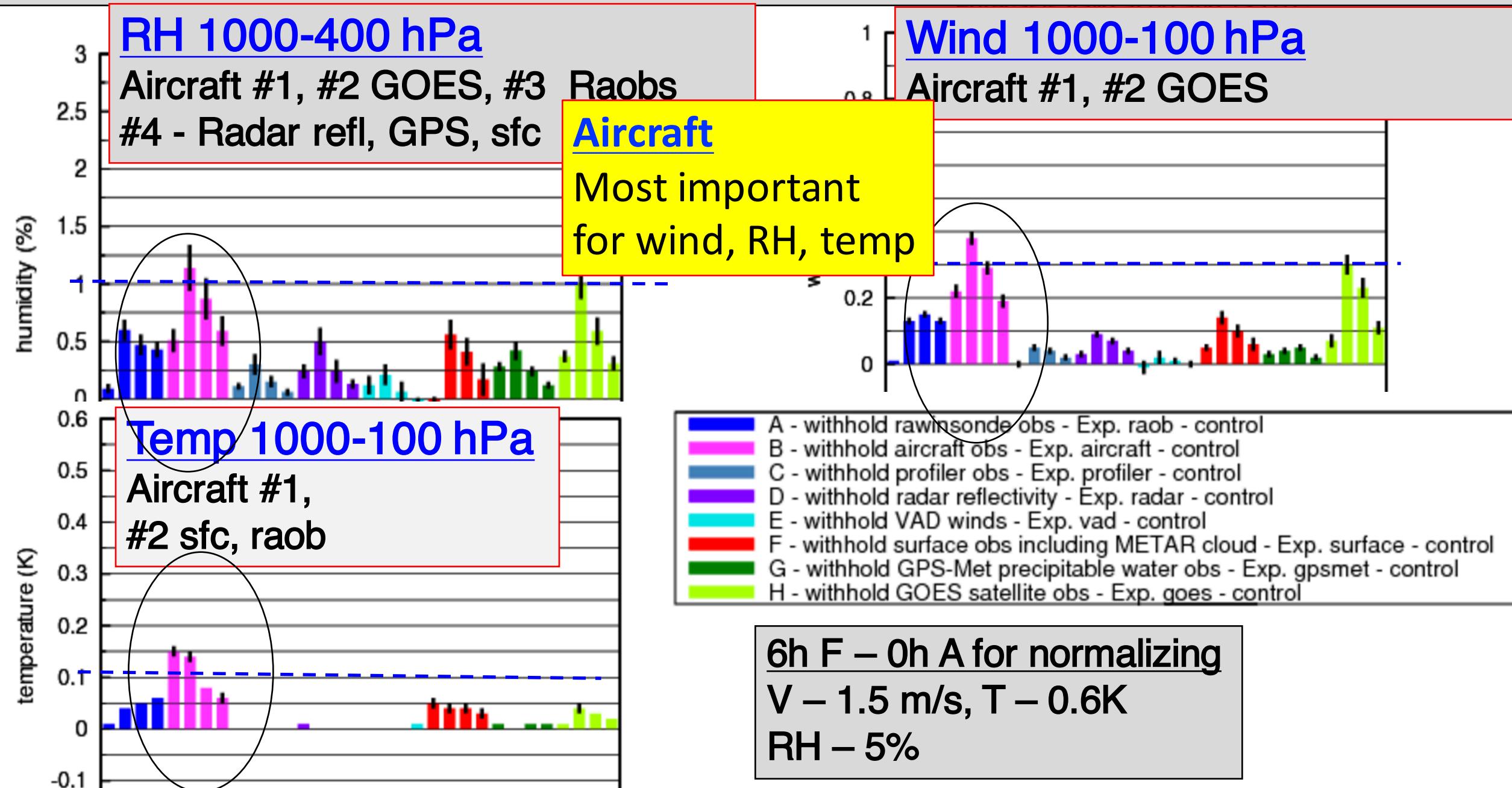
- ~30% of aircraft impact improvement is from aircraft RH/obs. (Rest from a/c wind)
- Enroute aircraft obs provide little additional value

## Experiments

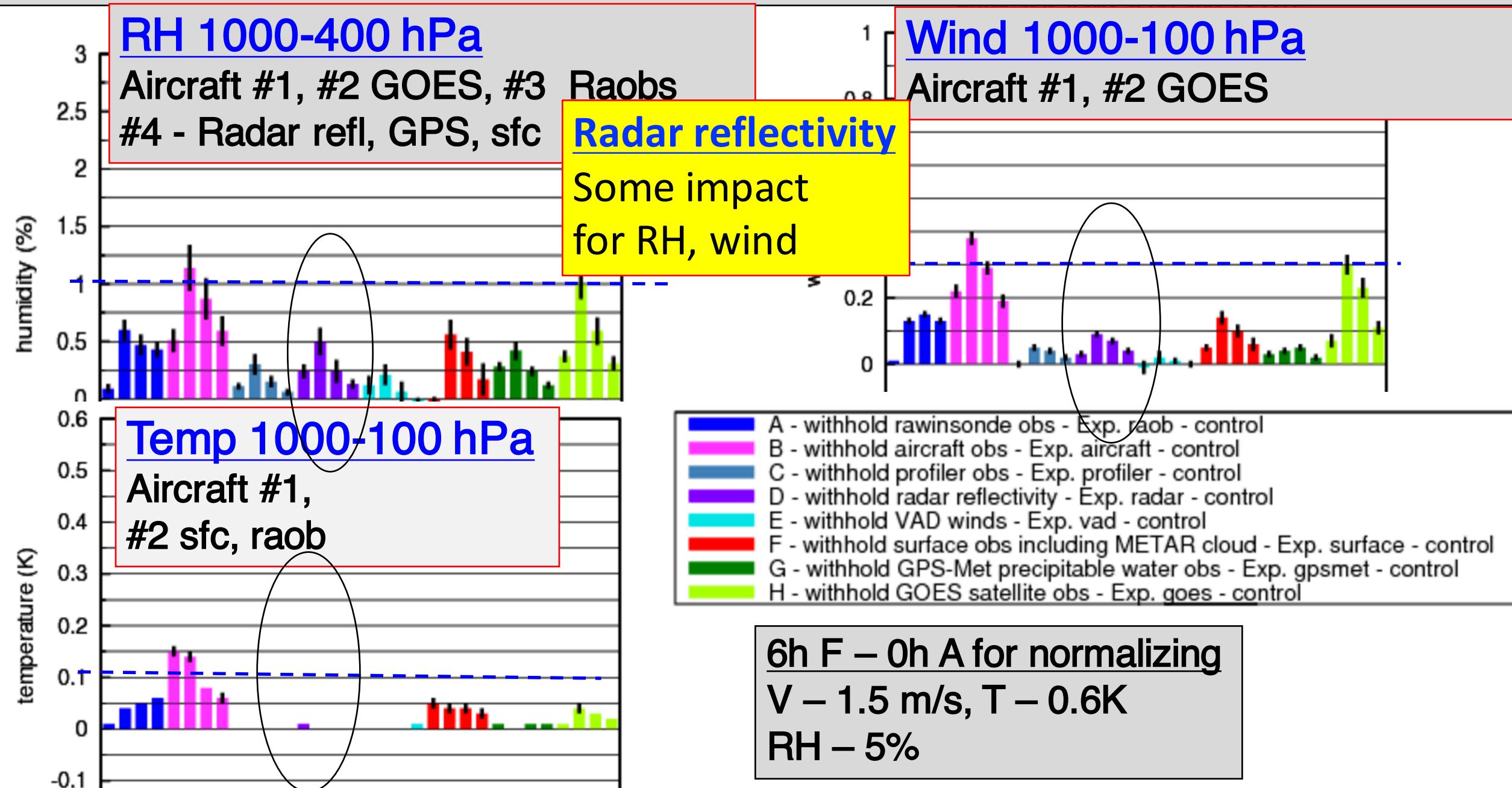
- Aircraft related
  - B – withhold all aircraft
  - C – withhold only a/c < 350 hPa
  - D – withhold only a/c > 350 hPa
  - E – withhold a/c temp/humidity

- A - withhold rawinsonde obs - Exp. raob - control
- B - withhold aircraft obs - Exp. aircraft - control
- C - withhold aircraft obs above 350 hPa - Exp. aircraft ABOVE350 - control
- D - withhold aircraft obs below 350 hPa - Exp. aircraft BELOW350 - control
- E - withhold aircraft temp/humidity obs - Exp. aircrafttempRH - control
- F - withhold surface obs including METAR cloud - Exp. surface - control

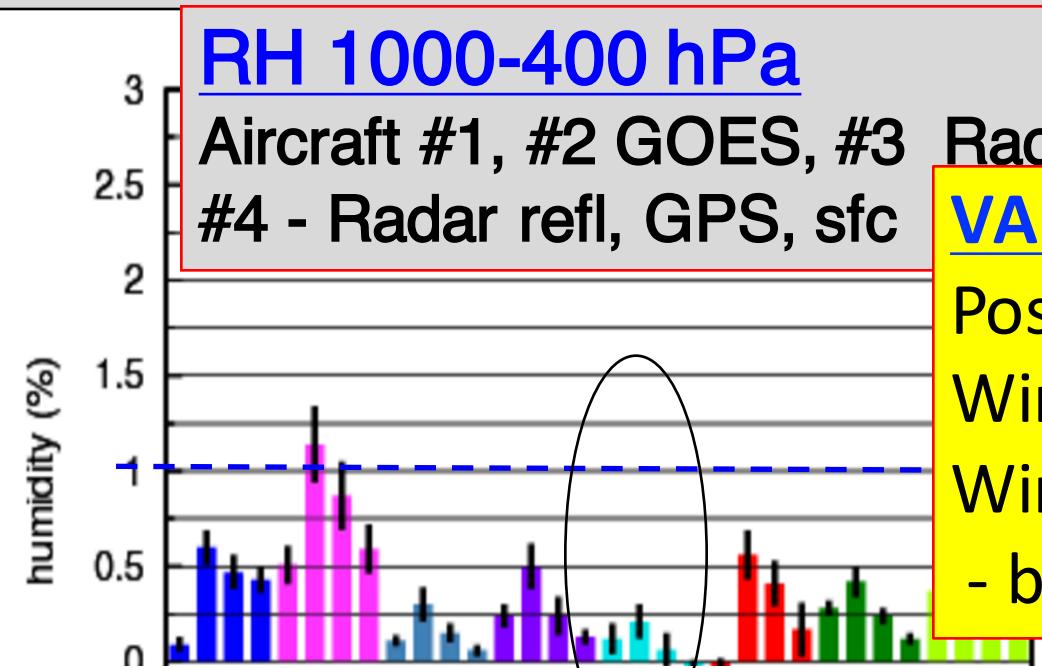
# Summary - N. America, 3h/6h/9h/12h, 12z+00z, RAP



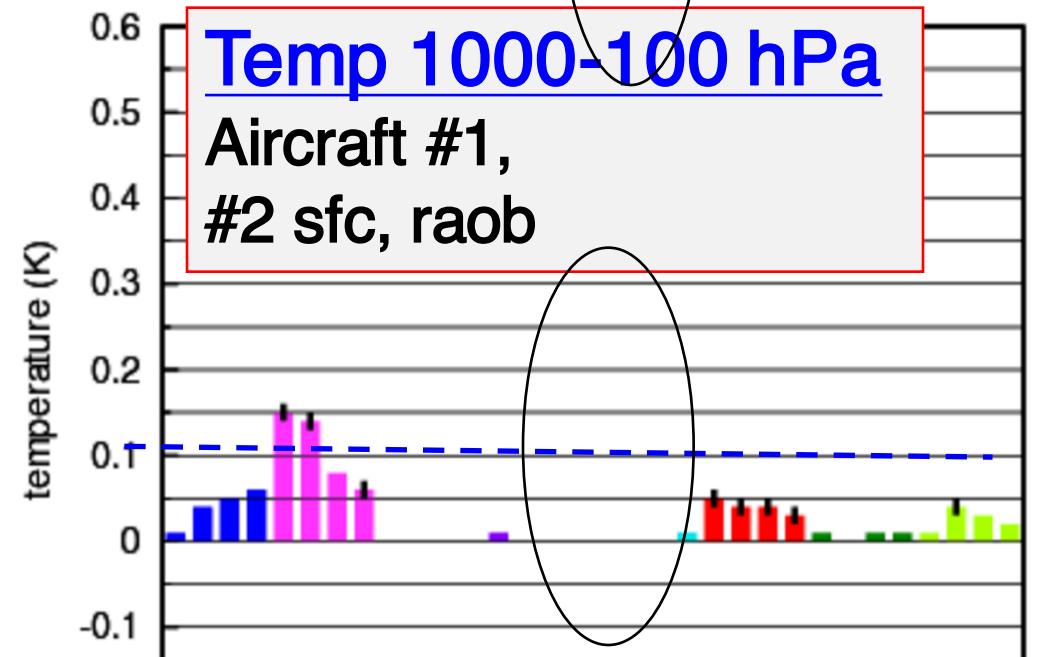
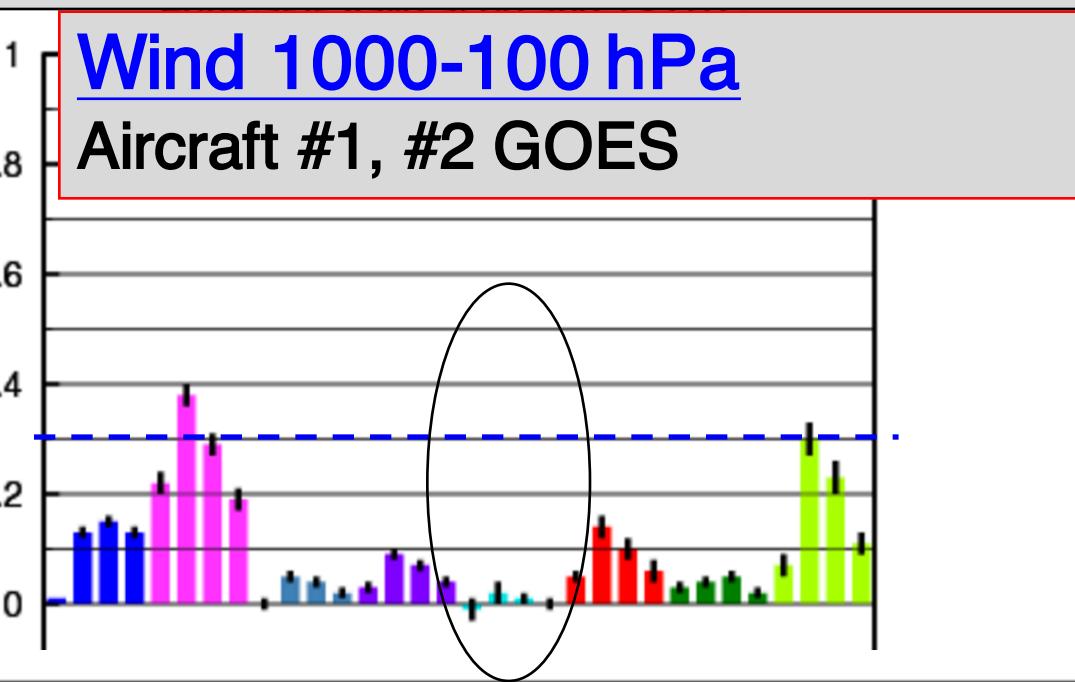
# Summary - N. America, 3h/6h/9h/12h, 12z+00z, RAP



# Summary - N. America, 3h/6h/9h/12h, 12z+00z, RAP



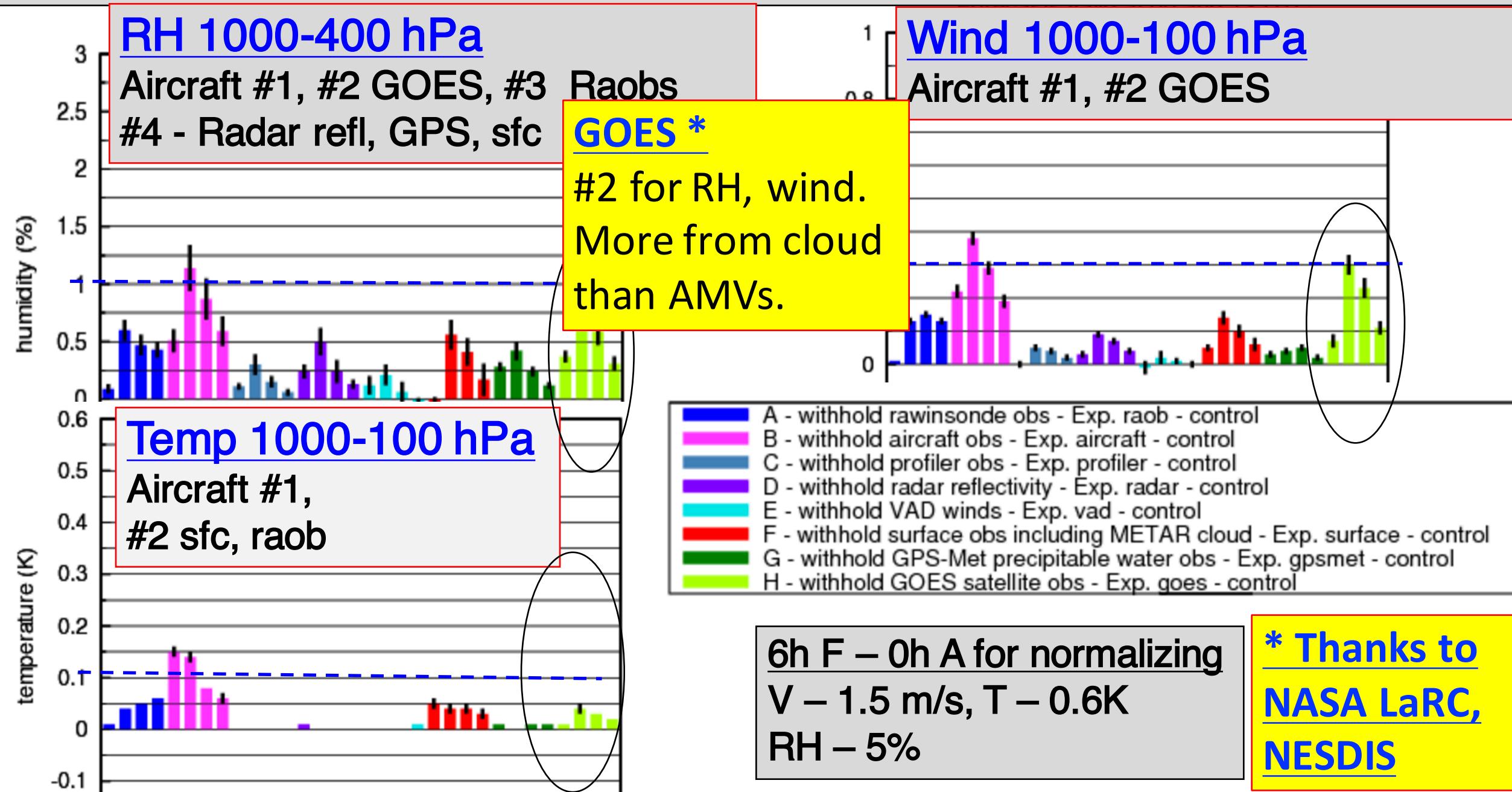
VAD winds  
Pos for RH,  
Wind+ (day)  
Wind- @night  
- birds



- A - withhold rawinsonde obs - Exp. raob - control
- B - withhold aircraft obs - Exp. aircraft - control
- C - withhold profiler obs - Exp. profiler - control
- D - withhold radar reflectivity - Exp. radar - control
- E - withhold VAD winds - Exp. vad - control
- F - withhold surface obs including METAR cloud - Exp. surface - control
- G - withhold GPS-Met precipitable water obs - Exp. gpsmet - control
- H - withhold GOES satellite obs - Exp. goes - control

6h F – 0h A for normalizing  
V – 1.5 m/s, T – 0.6K  
RH – 5%

# Summary - N. America, 3h/6h/9h/12h, 12z+00z, RAP



# Conclusions – Latest 2015 RAP OSE experiments

- Extensive [obs impact study](#) performed for summer retro period using [RAP](#) for 3-12h forecast impact
- [Heterogeneous](#) observing system in US effective for short-range (3-12h) forecasts for tropospheric RH, temp, winds.
  - Stronger wind-moisture cross-covariance with GSI in RAP than with RUC 3dVAR
- [Aircraft data most important observation overall](#) for short-range fcsts from tropopause-to-sfc (20-30% reduction for 6h fcst err for T/V/RH), but [far from sole key observing system](#).
  - GOES cloud/AMVs – combined - #2 for RH and winds in this recent study
  - For [RAP](#) OSEs (w/ ensemble/hybrid GSI assimilation) – broader contribution evident from different obs systems - [GPS-PW](#), [surface](#), radar reflectivity, RAOB
  - Increased RH and wind effect for aircraft from GSI with hybrid/EnKF DA

RAP model/assimilation description/results  
2016, *Mon. Wea. Rev.*, Benjamin et al.